Power Technology Branch
Army Power Division
US Army RDECOM CERDEC C2D
Fort Belvoir, Virginia

APPT – TR – 06 – 01

42nd Power Sources Conference: Smart Fuel Cell C20-MP Hybrid Fuel Cell Power Source

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
12 JUN 2006	**Final Technical Report**	**01-06-2005 to 12-06-2006**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
42nd Power Sources Conference Smart Fuel Cell C20-MP Hybrid Fuel Cell Power Source	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Pavel Fomin; Elizabeth Bostic	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
U.S. ARMY COMMUNICATIONS-ELECTRONICS RESEARCH DEVELOPMENT AND ENGINEERING CENTER,10125 Gratiot Rd.,Suite 100,Fort Belvoir,VA,22060-5816	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S. ARMY COMMUNICATIONS-ELECTRONICS RESEARCH DEVELOPMENT AND ENGINEERING CENTER, 10125 Gratiot Rd., Suite 100, Fort Belvoir, VA, 22060-5816	**AMSRD-CER-C2-AP-PT**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) **APPT-TR-06-01**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The SFC C20-MP now utilizes fourth generation conductive membrane technology in order to both increase system power density and mitigate the effects of methanol crossover across the DMFC membranes. Upon delivery of the upgraded units, CERDEC performed a series of test regimes to determine the operational capabilities of the C20-MP including fuel efficiency and power energy density. These tests confirmed that the C20-MP units are capable of achieving net system efficiencies as high as 21% based on the LHV of methanol. Testing also showed that the SFC systems were capable of providing upwards of 20 Watts of net continuous power at a power density of 10.25 Watts/kg. The calculated system energy density is 420Whrs/kg for a 72 hour, 20 Watt mission. The rest of this paper will discuss the results and findings in greater detail.

15. SUBJECT TERMS
direct methanol fuel cell ; DMFC ; test and evaluation ; U.S. Army research ; soldier power ; fuel cells

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**5**	

Smart Fuel Cell C20-MP Hybrid Fuel Cell Power Source

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Abstract

The Communications Electronics Research Development and Engineering Center's (CERDEC) Army Power Division initiated a system development program with Smart Fuel Cell (SFC) in 2003. At that time, CERDEC took delivery of the SFC A25 unit capable of producing a continuous power output of 25 watts with a system efficiency of 13%. Based on that effort, CERDEC awarded another contract and in 2004 received the SFC C25 system. Like the A25, this unit continuously produced a 25 watt power output but reduced the system weight by 83%. In 2005, SFC delivered two of its second generation 20W Hybrid Fuel Cell Power Sources (SFC C20-MP) to CERDEC for preliminary test and evaluation purposes.

Initial test results of the C20-MP showed a 19% efficiency and a calculated system energy density of 400 Whrs/kg. In order to improve system performance, CERDEC funded a system upgrade which included the integration of next generation fuel cell membranes. The upgraded system incorporates state-of-the-art direct methanol fuel cell technology. The SFC C20-MP now utilizes fourth generation conductive membrane technology in order to both increase system power density and mitigate the effects of methanol crossover across the DMFC membranes.

Upon delivery of the upgraded units, CERDEC performed a series of test regimes to determine the operational capabilities of the C20-MP including fuel efficiency and power energy density. These tests confirmed that the C20-MP units are capable of achieving net system efficiencies as high as 21% based on the LHV of methanol. Testing also showed that the SFC systems were capable of providing upwards of 20 Watts of net continuous power at a power density of 10.25 Watts/kg. The calculated system energy density is 420Whrs/kg for a 72 hour, 20 Watt mission. The rest of this paper will discuss the results and findings in greater detail.

Background

In June of 2002, the Department of the Army created Program Executive Office (PEO) Soldier. The primary purpose of this organization is to develop and field the best possible equipment for today's Soldier. To accomplish this task, a new and innovative approach was used that involved looking at the modern soldier as a system and ensuring that all equipment the Soldier used and carried on battle field worked together as part of an integrated system.

Transforming the Soldier into a system involves integrating many advanced electronic devices that consequently created a high demand for primary and rechargeable batteries. Providing power for this equipment created a heavy burden on the dismounted Soldier and significantly reduced the Soldier's fighting capability. Power sources make up a big significant percentage of weight carried by the Soldier. As an example, the battery weight associated for a 24 hour mission of a typical Dismounted Battle Combat Soldier (DBCS), could amount to as much as 17% of the overall weight.

The future Soldier will be electronic and the overall power demand is expected to increase. In the near future, it is possible that batteries will not be able to meet the high power requirements and for this reason CERDEC has been developing advanced high energy density power sources.

Introduction

To ease the logistics burden and meet the demand of reliable high energy density light weight power, CERDEC's Fuel Cell Technology Team has been evaluating fuel cell power sources from various commercial vendors. One of these vendors has been Smart Fuel Cell (SFC) of Brunnthal-Nord, Germany.

Since 2003, CERDEC has had ongoing contracts with SFC to develop a lightweight, silent, Direct Methanol Fuel Cell (DMFC) system capable of sustaining soldier power demand in the 20 watt range. The first unit, the A25, was a 25 watt hybrid fuel cell weighing 10 kg. Although not practical for military operations, the A25 provided valuable insight into fuel cell design and was used as the basis for SFC's next generation unit, the C25. This unit had a dry weight of 1.7 kg and provided an 83%

weight reduction while at the same time doubling the energy density. SFC then took this one step further and developed the C20-MP with Gen IV technology.

C20-MP w/ Gen IV Technology

The C20-MP is a 20 watt hybrid DMFC system with a dry weight of 1.9 kg and a calculated energy density of 430 W-hr/kg for a 72 hour operational cycle. Because power is trasmitted through an internal rechargeable battery, the unit is capable of producing instant power at the switch of a button. However, the fuel cell, which charges the internal battery, has a start time of approximately 1.5 minutes; it is at this time that the unit is fully operational. The C20-MP comes with advanced system level functions such as status display, error display and operational mode.

System Specifications

The C20MP is a complete packaged system capable of providing instant power. Figure 1 shows the various system features.

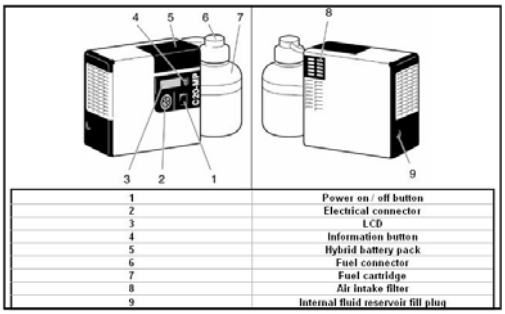

Figure 1. SFC Diagram

Fuel is supplied by 500ml hot swappable cartridges that screw on to the connection valve and are capable of providing a constant 20 watt power output for 24 hours. Table 1 provides detailed weight measurements of each component.

System Dry Weight	1704.90	**g**
Internal Battery	223.74	**g**
Full Fuel Cartridge	472.24	**g**
Empty Fuel Cartridge	89.54	**g**
Total Weight (24hrs)	2.40	**kg**
Total Weight (72hrs)	3.35	**kg**

Table 1. System Weight Breakdown

Testing – CERDEC Test Plan

The CERDEC test plan included a variety of system and environmental evaluations totaling twelve individual tests. When applicable, tests were repeated multiple times to ensure accuracy as well as adherence to testing procedure. The twelve individual tests can be grouped into the following four main categories: Fuel Consumption, Electrical Characterization, Orientation, and Environmental Testing. Data was logged both manually and electronically to prevent data loss.

Testing Results –Summary

Two (2) C20MP units, Unit 1 and Unit 2, were evaluated for a combined total of 580 hours at CERDEC. Testing results showed a peak efficiency of 21% at a 20 watt load and a fuel consumption rate of 19.88 ml/hour. The units are capable of producing a peak power output of 35 watts for three (3) minutes. Successful startup was demonstrated at 1˚C and the unit was shown to operate up to a temperature of 40˚C before being shut off by an internal safety control mechanism.

The units are capable of being operated upright, 90˚ incline backwards, and 45˚ in the left or right direction without any operational degradation. Noise emission was in line with SFC claims ranging from 47-50 dB(A) at a one meter distance.

Testing Results – Efficiency

Overall, both units peaked at a 21% efficiency at full rated power. Figure 2 shows the lowest recorded efficiency occurred during a 25% load (5 watts) test in which the unit demonstrated a net efficiency of 6.7% based on the LHV of methanol.

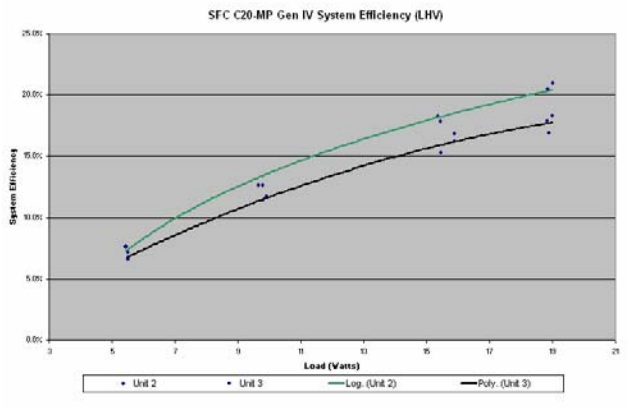

Figure 2. Efficiency Graph

Testing Results – Fuel Consumption

Figure 3 shows fuel consumption ranging from a minimum of 16.3 ml/hour at 5 watts all the way to 24.54 ml/hour during a 20 watt load test. The average fuel consumption between the 5-20 watt load tests was 18.49 ml/hour. It is also significant to note, that neither

orientation nor environmental temperature testing significantly affected fuel consumption rates.

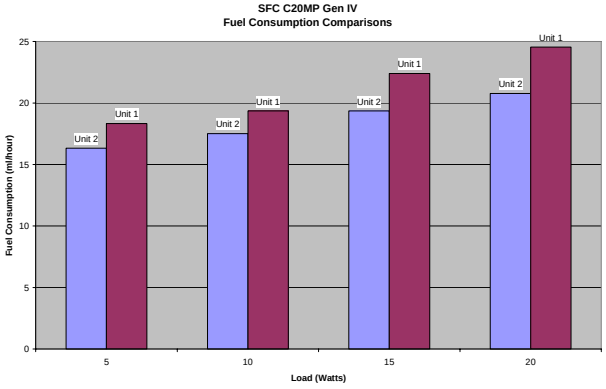

Figure 3. Fuel Consumption Graph

Testing Results – Voltage Characterization

Figure 4 displays a polarization graph of both units. Even with the power output ranging from 25-100% load; the system voltage was stable and remained in the range of 12-12.6 V.

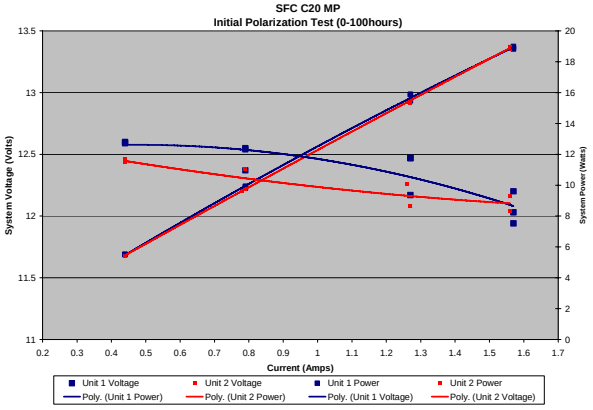

Figure 4. Polarization Graph

Because the C20-MP units are hybrid fuel cell power sources, it is difficult to perform standard fuel cell voltage characterization testing due to interference from the internal battery. The following limited results were obtained.

Min Voltage @ Start up	10.39	V
Average Voltage @ Start up	12.63	V
Max Voltage Rise @ 100%	18.18	V
Max Voltage Rise @ 75%	17.91	V
Max Voltage Rise @ 50%	17.28	V
Max Voltage Rise @ 25%	16.46	V
Min Voltage Dip @ 100%	10.89	V
Min Voltage Dip @ 75%	10.93	V
Min Voltage Dip @ 50%	10.93	V
Min Voltage Dip @ 25%	11.07	V

Table 2. Voltage Characterization

Testing Results – Lifetime

Both units, Unit 1 and 2 were exposed to lifetime testing at the end of the general test cycle. System voltage degradation was first noticed after approximately 50 hours into the lifetime test. At that time, both units had difficulty providing a constant 20 watt power output at which point the load was adjusted to 15 then 10 and finally 5 watts. After approximately 280 hours, both units were not capable of providing a power output. SFC states that system voltage degradation is a result of component breakdown as opposed to actual stack failure. Figure 5 and 6 show the lifetime testing graph of both units.

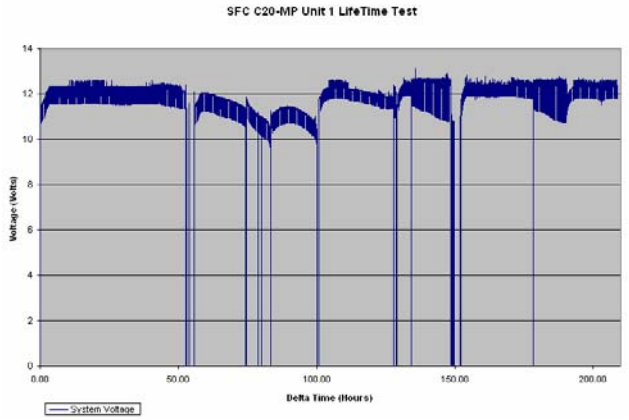

Figure 5. Unit 1 Lifetime Testing Graph

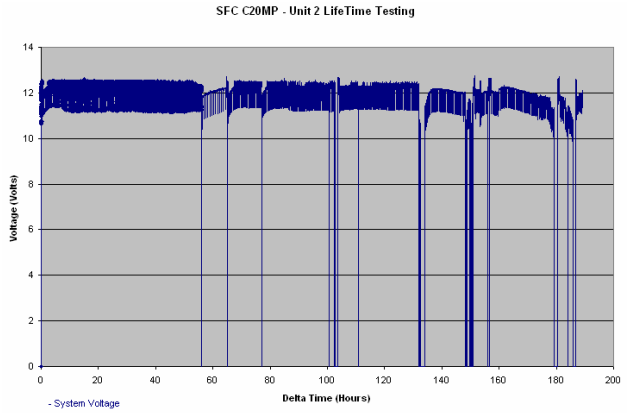

Figure 6. Unit 2 Lifetime Testing Graph

Testing Results – Thermal Display

Figure 7 and 8 shows the following thermal display observed during a constant 15 watt power output from the rear exhaust panel. No significant thermal reading was noticed at any other side of the C20-MP fuel cell unit.

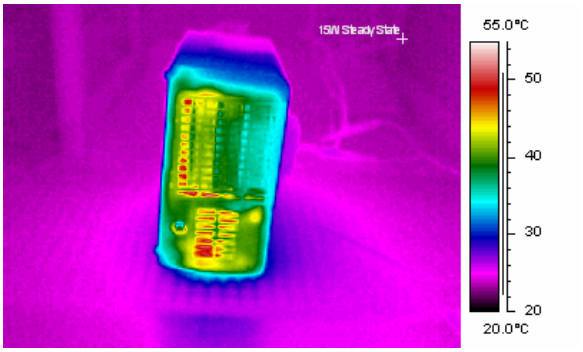

Figure 7. 15 watt Infrared Image
(Courtesy of Tony DeAnni & Terrill Atwater
CERDEC – Army Power Division)

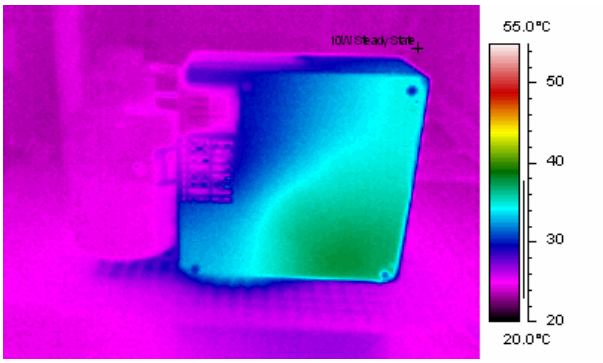

Figure 8. 10 watt Infrared Image
(Courtesy of Tony DeAnni & Terrill Atwater
CERDEC – Army Power Division)

Testing Results – Testing Problems

Throughout the course of testing, CERDEC test engineers experienced certain technical difficulties when evaluating the C20-MP units. Most of the time, these errors stemmed from secondary components (i.e. fuel and circulator pump) rather than primary component breakdowns. It was noted, that the lithium-ion battery used for peak power and start up had a high self discharge rate. This in part is due to the protection circuitry embedded in the fuel that system that is essential for safe operation. Currently, the discharge rate does offer a significant limiting factor to prolonged operation; however SFC is well aware of the issue and is already making modifications to be incorporated in their next generation units.

CERDEC test engineers also experienced moderate errors associated with water management and fuel line air exposure that prevented fuel from reaching the stack. Most of these errors were corrected without significant repair however certain component breakdown required specialized maintenance from SFC. Although SFC specifies that the C20 units are capable of providing 1,000 hour of run time operation, CERDEC has only observed a run time of approximately 1/3 of that, 280 hours with Unit 1 and 300 with Unit 2, before requiring specialized maintenance upgrade from SFC.

Overall, the C20MP units performed well under limited conditions. Many prior errors stemming from on/off cycle operation as well as stack failure have been eliminated with only minor systematic errors remaining. SFC is currently performing internal lifetime as well component analysis testing that will be used to reduce the number of component failures. SFC demonstrates a clear path to overall system development and is addressing many of the known issues with their next generation of portable power units.

Testing Results – Military Significance

Military significance was also evaluated based on the increased capability that the technology offered to the Warfighter. As mentioned earlier, current Soldier power is supplied via rechargeable or primary batteries. The most widely used military specific battery; the BA-5590 has a weight of 1 kg and provides 180 watt hours of power. The Li-145, a possible alternative to the BA-5590, also weighs 1 kg and provides 145 watt hours of power. As shown in Figure 9, for PEO Soldier's Land Warrior program, seven (7) Li-145 batteries are required for a three day soldier mission totaling in 7 kg of battery weight. Under the same conditions, the SFC C20-MP and associated fuel weighs only 3.5 kg while providing the same power. This demonstrates a 50% weight reduction and offers several logistic advantages such as eliminating the need for battery recharge time.

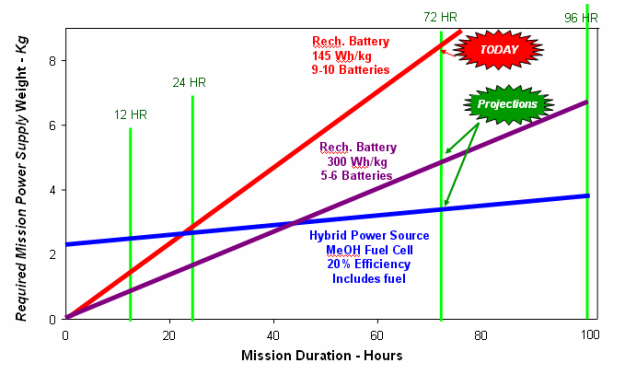

Figure 9. Weight vs. Mission Length
(Courtesy of PM SWAR)

Conclusion

As the traditional battlefield is transformed into a modernized digital arena, power is an increasingly limiting factor in mission capability. The SFC C20-MP has demonstrated good progress towards meeting the growing power demand on the battlefield. CERDEC will continue to play its key role in developing future power sources that will meet the growing power demand and transition technology to the Warfighter quicker.